EXHIBIT B

Applications of location-based services: A selected review

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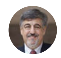
Georg Gartner
TU Wien



Chris Rizos
UNSW Sydney

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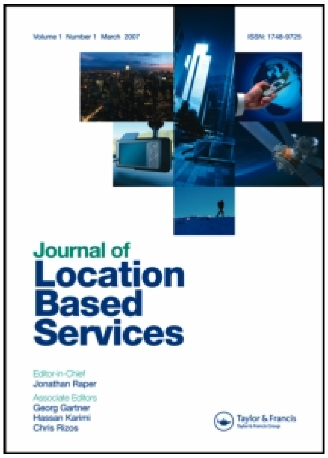

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Jonathan Raper [a]; Georg Gartner [b]; Hassan Karimi [c]; Chris Rizos [d]
[a] Information Science, Northampton Square, City University, London, UK
[b] Department of Geoinformation and Cartography, Vienna University of Technology, Erzherzog-Johannplatz 1, Austria
[c] University of Pittsburgh, PA, USA
[d] School of Surverying 2 SIS, University of New South Wales, Sydney, Australia

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REVIEW ARTICLE

Applications of location–based services: a selected review

Jonathan Raper[a]*, Georg Gartner[b], Hassan Karimi[c] and Chris Rizos[d]

[a]*Information Science, Northampton Square, City University, London, EC1V OHB, UK;* [b]*Department of Geoinformation and Cartography, Vienna University of Technology, Erzherzog–Johannplatz 1, Vienna A–1040, Austria;* [c]*University of Pittsburgh, PA, USA;* [d]*School of Surverying 2 SIS, University of New South Wales, Sydney, 2052, Australia*

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This article reviews a selected set of location–based services (LBS) that have been published in the research literature, focussing on mobile guides, transport support, gaming, assistive technology and health. The research needs and opportunities in each area are evaluated and the connections between each category of LBS are discussed. The review illustrates the enormous diversity of forms in which LBS are appearing and the wide range of application sectors that are represented. However, very few of these applications are implemented pervasively on a commercial basis as this is still challenging technically and economically.

Keywords: mobile guides; location–based gaming; intelligent transport systems

1. Introduction

In this second Editorial Lead Paper for the Journal of Location Based Services (JLBS) we aim to review a selection of published applications studies in the field and assess the way they implement the theoretical developments discussed in the first Editorial Lead Paper (Raper *et al*. 2007). The distribution of the papers found in a thorough but selective literature review is also assessed as an indication of the real domain of utility for LBS and to indicate where further theoretical work is needed. This work is intended to be inclusive of all disciplines in which location can be a driver for information selection, processing and delivery, so that the Journal can facilitate the exchange of experiences between application sectors developing LBS.

2. Literature review

Inevitably in such a fractured and multi-disciplinary field, many applications will have escaped our attention or will lie in the gap between implementation and appearance in the literature. This review is being completed in the second half of 2007 and represents the state of knowledge as close to this date as possible. However, note that this review only

*Corresponding author. Email: raper@soi.city.ac.uk

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covers the published literature, and no material from white papers or online presentations is included as it is impossible to know the origin or validity of some (much?) of this material. It is a medium term aspiration of this Journal to establish an online repository/link library of this 'grey literature', so that it may be accessed and read on a 'caveat emptor' basis, and curated for the long term when patent disputes may make such documentation particularly important.

The rest of this article reviews the key areas where LBS technology has been influential, looking at established areas such as mobile guides and intelligent transport systems as well as emerging areas such as location-based gaming, assistive technology and location-based health applications.

3. Mobile guides

The largest group of LBS applications is in a field known as 'mobile guides'. A mobile guide can be defined as a portable, location-sensitive and information-rich digital guide to the user's surroundings. This definition covers a wide range of designs and usage situations, which can be classified and evaluated in a variety of different ways. Most mobile guides are offering new services to users, but a part of all mobile guides is the potential replacement of paper guides and map books. This has opened a debate about what functions are best provided on paper or digitally, with the update rate and need for spatial precision being the best discriminators. Most paper guidebooks are published no more than annually and do not have built-in positioning, which creates a natural opportunity for digital mobile guides to fill.

A survey of mobile guides by Baus *et al.* (2005) characterised them by:

- Geopositioning (whether GPS, wifi or other)
- Architecture (client-server or distributed applications)
- Situational factors (focussed on what the user is doing and how this changes)
- Adaptation (e.g. handling varying positional quality)
- Interface (multi-modal or text/pointing systems)
- Network access (whether connected or using local caching)
- Maps used (map interfaces on a small screen should be schematised if possible)

Baus *et al.* (2005) argued that the greatest future potential lay in collaborative usage of mobile guides where users are able to view the tracks and recommendations of colleagues, i.e. mobile social networking.

Kruger *et al.* (2007) reviewed 'adaptive mobile guides' with a navigation focus, which they considered to be classic examples of context-sensitive applications. They divided mobile guides into the following categories:

- Resource adapted– optimised in advance for regular patterns of usage
- Resource adaptive– rely on a single strategy for resource usage
- Resource adapting– has ability to adapt to resource situations using multiple strategies

They argued that these categories of adaptation are particularly important for location determination (where the outdoor/indoor transition requires a switch between methods), and for situational responsiveness. They further explore modelling of users, context and

situations as drivers for adaptation through the use of the conceptual model UBISWORLD, the user markup language UserML and the ontology model Gumo.

Kruger *et al.* (2007) developed a further classification of indoor and outdoor mobile guides (including shopping guides not considered here) along the following axes:

- Adaptivity (using the Kruger *et al.* 2007 template)
- Geopositioning (GPS or wifi outdoors, infrared indoors)
- Knowledge representation (relational model or ontology model)
- Number of users (mostly one)
- User model (based on stereotypes, user preferences or UBISWORLD)
- Social context (multi-user approach)
- Presentation metaphor (map, virtual model, book, kiosk)
- Platform (PDA, phone, kiosk)

However, this classification is strongly influenced by the user modelling approach, and it does not evaluate whether the information is pushed or pulled by the user, the spatio-temporal expression of the location-based content, or the use case for the system.

Based on a wide survey of the many systems now being built, and building on these previous classifications, it is argued here that the canonical axes of comparison for mobile guides should be defined from a broader perspective. It is argued therefore that the following factors should be used to characterise mobile guides:

- Positioning quality (focussing on the accuracy and pervasiveness of the technology)
- Architecture (client-server or distributed applications)
- Presentation metaphor (map, web page, book, kiosk, AR, VR)
- Content relevance (geographic and semantic relevance of the content for the user)
- Delivery (focussing on whether the user actively selects or passively receives)
- Use case (whether navigation, mobile search, tour etc.)
- Adaptivity (using the Kruger *et al.* 2007 template)

Though a classification with seven axes is complex, and some of these axes are part-correlated (e.g. presentation metaphor and use case), by classifying the existing mobile guides, patterns of design choices and evolution through time can clearly be seen. Searching the current JLBS bibliography of ~500 research publications yields 34 mobile guides that have progressed beyond temporary laboratory existence, been tested with real users and published in the literature. This is an approximation of the total number of mobile guides as some have been developed and not published, some lack distinguishing characteristics, e.g. a screen, and others such as commercial personal navigation devices have proprietary and unpublished architectures and limited informational features and so cannot be evaluated easily.

The list of mobile guides has been clustered using two different strategies to explore the commonalities, firstly by architecture/positioning, secondly by use case, and the resulting groupings are discussed below and shown in Tables 1 and 2. As the scoring of the mobile guides is based on published (and interpreted) information, the groups are inherently conjectural, however, the exercise serves to erect some hypotheses that may be tested by further analysis. The citations to each of the systems mentioned are in the tables.

Table 1. Mobile guides classified by architecture and presentation.

Short Name	Application	Positioning	Architecture	Presentation	Content relevance	Delivery	Use case	Adaptivity	Publication
Cyberguide	Tourism	GPS/IR	Client/server	Map/book	Around Me	Pull	Mobile Search	Adapted	Abowd *et al.* (1997)
Guide	Tourism	WiFi/self	Client/server	Book/map	Around Me	Push	Mobile Search	Adapting	Davies *et al.* (1999)
Cooltown	Tourism	IR	Client/server	Book/map	Around Me	Push/pull	Mobile Search	Adapting	Kindberg *et al.* (2000)
DeepMap	Tourism	WiFi	Client/server	Map/book	Around Me	Push	Tour	Adapting	Malaka and Zipf (2000)
Hypergeo	Tourism	GPS	Client/server	Map/book	Around Me/ahead	Pull	Mobile Search	Adapting	Mountain & Raper (2000)
Lol@	Tourism	GPS/self	Client/server	Map/book	Around Me	Push/pull	Tour	Adapted	Pospischil *et al.* (2002)
CRUMPET	Tourism	GPS	Client/server	Map/book	Around Me	Pull	Tour	Adapted	Schmidt-Belz *et al.* (2003)
WebPark	Tourism	GPS	Client/server	Map/book	Around Me/ahead	Pull	Mobile Search	Adapting	Edwardes *et al.* (2003)
Tourist Guide	Tourism	GPS/DGPS	Client/server	Map/book	Around Me	Push/pull	Mobile Search	Adapted	Simcock *et al.* (2003)
Ambiesense	Tourism	Tags	Client/server	Map/book	Around Me	Push/pull	Mobile Search	Adaptive	Göker *et al.* (2004)
TGH	Tourism	GPS	Client/server	Map/book/speech	Around Me	Pull	Mobile Search	Adapting	Yue *et al.* (2005)
Tellmaris	Transport	GPS/self	Client/server	Map/VR	Around Me	Pull	Navigation	Adapted	Schilling *et al.* (2005)
MobileSeoulSearch	Tourism	GPS	Client/server	Map/book	Around Me	Pull	Mobile Search	Adaptive	Kwon *et al.* (2005)
GIMODIG	Recreation	GPS	Client/server	Map	Route	Pull	Navigation	Adapting	Sarjakoski *et al.* (2005)
MUMS	Transport	GPS	Client/server	Map	Route	Pull	Navigation	Adapted	Topi (2006)
Wigglestick	Tourism	GPS	Client/server	Map/book	Around Me	Pull	Mobile Search	Adaptive	Jimison *et al.* (2007)
Camineo	Tourism	GPS/compass	Client/server	Map/book/AR/VR	Around Me/ahead	Pull/push	Mobile Search/tour	Adapting	M'tain & MacFarl'ne (2007)
Navitime	Transport	GPS/compass	Client/server	Map/book/VR	Route	Pull	Navigation	Adapting	Arikawa *et al.* (2007a)
Gullivers Genie	Tourism	GPS	Client/server	Map/book	Around Me	Push/agent	Mobile Search	Adaptive	O'Grady *et al.* (2005)
MARS	Tourism	GPS	Client/server	Video imagery	AR	Push	Mobile Search	Adapted	Feiner *et al.* (1997)
Museum Wearable	Museum	IR	Client/server	Video imagery	AR	Push	Tour	Adapting	Sparacino (2002)
PEACH	Museum	IR/WiFi	Client/server	Video imagery	Authored	Push	Tour	Adapting	Rocchi *et al.* (2004)
Entertainment Guide	Tourism	GPS	Client/server	Video imagery	Around Me	Push/pull	Mobile Search	Adapting	Koutsiouris *et al.* (2007)
REAL	Transport	GPS/IR/compass	Broadcast	Map/speech	Around Me/AR	Push/pull	Navigation	Adapting	Baus *et al.* (2002)
Sotto Voce	Museum	WiFi	Broadcast	Book/speech	Around Me	Push	Tour	Adapted	Aoki *et al.* (2002)
BPN	Transport	GPS/IR	Broadcast	Map/speech/VR	Route	Push	Navigation	Adapting	Krüger (2004)
Syren	Museum	GPS/compass	Broadcast	Soundscape	Authored	Push	Tour	Adapted	Woo *et al.* (2004)
LISTEN	Museum	WiFi	Broadcast	Soundscape	Around Me	Push	Tour	Adaptive	Eisenhauer *et al.* (2005)
PhoneGuide	Tourism	Tags	Event trigger	Video imagery	AR	Pull	Mobile Search	Adapted	Möhring *et al.* (2004)
Marble Museum	Museum	IR/tags/gesture	Event trigger	Map/book/speech	Around Me	Push/pull	Tour	Adaptive	Santoro *et al.* (2007)
Minotour	Tourism	GPS	Event trigger	Map/book/speech	Authored	Push	Tour	Adaptive	Hecht *et al.* (2007)
WikiEye	Tourism	Self/gesture	Event trigger	Map/book	Authored	Push	Mobile Search	Adaptive	Hecht *et al.* (2007)
MOBE	Tourism	WiFi/Tags	Applets	Map/book	Around Me	Push	Mobile Search	Adapting	Coppola *et al.* (2004)
Taeneb City Guide	Tourism	WiFi/self	Sync	Map/book	Around Me	Pull	Mobile Search	Adapted	Dunlop *et al.* (2004)

Table 2. Mobile guides classified by use case and delivery.

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WikiEye	Tourism	Self/gesture	Event trigger	Map/book	Authored	Push	Mobile Search	Adaptive	Hecht *et al.* (2007)
MOBE	Tourism	WiFi/Tags	Applets	Map/book	Around Me	Push	Mobile Search	Adapting	Coppola *et al.* (2004)

3.1. *Classification by architecture and presentation*

Dividing the 34 mobile guides by system architecture produces three groups and two individual outliers. Since one of these groups consists of more than half the systems, this largest group was divided once more by presentation type into those systems using maps and those using video imagery. The result is four groups and two individual outliers.

The largest group in this classification can be perhaps considered to contain the archetypal mobile guide: a GPS positioned, client-server solution with map presentation and pull information delivery in which the user selects the content and display on an ongoing basis. However, before client/server technology matured sufficiently for mobile solutions, CyberGuide, Guide and Deep Map all defined *ad hoc* architectures based on message-passing, object oriented software and distributed processing respectively. Hypergeo may have been the first system to use a mini web portal on the device extended to handle position, however, many subsequent mobile guides have implemented a wide variety of client-server approaches. The dominant approach to content relevance in this group is the 'around me' proximity filter: only Hypergeo and its descendents WebPark and Camineo have implemented other spatial filters such as 'look ahead' based on recent movement behaviour. The most advanced mobile guides now using this architecture (such as Navitime) are delivering location-based information across telecom networks to mobile phones with GPS and presenting situated VR models in real time. A final distinction that can be made in this category lies between the experimental systems such as Lol@, Crumpet and Tellmaris and the operational systems such as Ambiesense, GIMODIG, Camineo and Navitime, which are all in revenue earning service.

The second group (also based on client/server architecture) is composed of systems delivering live augmented reality displays or location-based video to support tours or local discovery. MARS is the classic antecedent system that defined the system components and the augmented reality concept, though at the time (1997) a rucksack and headset was needed to use the system! Only five years later in 2002, the Museum Wearable consisted of a shoulder bag and spectacles, and by 2004 PEACH was delivering personalised video in a museum on a PDA.

The third group of mobile guides in this classification are speech-oriented systems based on broadcast architectures, i.e. information is fed to the user in a stream after the task is defined. Some of these systems are authored tours or soundscapes delivered through mobile guides such as Sotto Voce or LISTEN, while others are speech-based navigation describers such as REAL and BPN.

The fourth group defined in this classification are 'event triggered' systems that deliver information on demand, for example, when scanning a RFID tag or reaching a node in a tour. These systems are the least 'adapting' systems using Krüger's classification as they can only respond in a pre-programmed way to the events. The increasing maturity of the collaboratively written Wikipedia has allowed Minotour and WikiEye to develop mobile guides based on the delivery of wiki entries at defined locations, though note that WikiEye is a tool to browse a map rather than real space.

Two mobile guides are architectural outliers in this classification. The Taeneb City Guide would belong in the first group but for its method of caching all content on the device with update by periodic sync operations. However, MOBE is a unique approach to mobile guides based on the location-based triggering of downloadable applets to provide customised information in a city environment where there is pervasive wifi coverage.

3.2. *Classification by use case and delivery*

If the 34 mobile guides are divided by use case then three groups are formed consisting of mobile search, tour and navigation cases. However, the mobile search case is much larger than the others: if this group is sub-divided by delivery then two sub-groups defined by push and pull approaches are formed to make four groups in all. Notably, in this classification, the application areas closely approximate the use case groupings, as might be expected.

The mobile search/pull group closely corresponds to the first group in the architecture and presentation classification and includes the classic early mobile guides such as CyberGuide and Hypergeo. This use case can be characterised as the 'GIS-in-the-hand' approach in which many of the designers have seen their aim as to move existing GIS functionality off the desktop onto the mobile device. Only the more recent Wigglestick has come up with new concepts in this use case suggesting that the role of a mobile guide is to augment and filter rather than 'map' the environment. In this group, the Camineo mobile guide (the commercial successor to WebPark) is the only system to be running in a variety of different places with different content. Delivering Camineo mobile guides in cycle touring, open air museums and national parks has shown the importance of geospatial content management systems for mobile guides. This is, as yet, an under researched challenge in this field.

The mobile search/push group can be characterised as 'urban markup' in which the mobile guide is the artefact that allows the user to browse the situated resources of the mobile web such as Wikipedia entries. There are differing architectural approaches to satisfying this use case such as the tag approach used by Ambiesense in which users get local content delivered by Bluetooth from installed mini servers or the downloadable applet approach of MOBE.

Mobile guides are also widely used as tour guides, especially in museums and are predominantly push-oriented. This third group of systems is very diverse in architecture and positioning terms, as developers have searched for the best way to augment 'the tour' with digital information. These systems are hard to compare as they mostly are only installed in one place, and only Minotour could be implemented anywhere with minimal customisation.

The fourth group of navigation-focussed systems are generally the richer pedestrian equivalent of the personal navigation devices (PND) (also known as 'satnav') available for cars. The massive commercial success of PNDs in cars has depended to a great extent on the well-defined nature of the 'driving use case'. The mobile guides in this group are examples of attempts to explore the pedestrian navigation use case: thus, BPN shows how the multimodal challenge can be met across driving and walking modes and GIMODIG shows how to deliver the right kind of map for the (outdoor leisure) activity being undertaken. However, Navitime is the undisputed leader in this group as it has almost 2 million users in Japan across all of the major mobile phone networks, and is functionally advanced with deep integration with public transportation information and a virtual reality interface option.

3.3. *Mobile guide research agenda*

One of the deep challenges associated with the creation of mobile guides is that they need to be 'invented': there are no analogue equivalents of many of the digital artefacts that are

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being created. This has placed a special focus on design and user needs studies, which have been conducted using ethnography, questionnaire approaches and formal requirements studies. The iPod-based maPodWalk (based on self-positioning) is an example of the kind of new forms of guide being considered (Arikawa *et al.* 2007b).

Brown and Laurier (2005) carried out an ethnographic study of map use to help inform the design of electronic maps and guides finding that collaborative use, localisation and intentional wandering were not well supported by the systems that had been developed. Ruchter *et al.* (2005) compared map and mobile guide usage by different groups walking in a nature reserve, finding that although there were few differences in performance, the mobile guide strongly motivated children, while the electronic maps were rated poorer than their paper counterparts. Krug *et al.* (2003) carried out a questionnaire survey on the information needs of nearly 1600 national park visitors as the first stage in the development of the WebPark project, finding that 54% expressed an interest in the prospective system. Of those expressing an interest, 55–75% agreed that real time position-fixing, the location of key park attractions and safety information would be 'very important' or 'important' in the prospective system. Although this was a solid basis for launching a system, 35% said that a 'virtual trail guide' was not necessary. This survey shows the contradictions and challenges of a consumer audience: there is a desire to have access to information but not if the technology is a barrier. May *et al.* (2003) carried out a requirements analysis on the information desired by potential users of a pedestrian navigation system finding that 72% of the cues identified as important were landmarks (and not street names or distances). Zipf and Joest (2004) carried out a survey on (young) user expectations of LBS, finding *inter alia* that users prefer rotating maps to static ones and that users would walk a maximum of 300–400 m to find a point of interest on a mobile guide.

Once a mobile guide has been built, a further challenge is to evaluate the system: in an important paper Kjeldskov *et al.* (2005 p. 52) undertook a comparative study of evaluation techniques as

> 'Mobile guides take many of the well-known methodological challenges of evaluating the usability of both stationary and mobile computer systems to an extreme'.

The use of multiple forms of evaluation on the same system shows a high level of agreement between methods, though a video analysis with detailed log files and usability evaluation is regarded as the gold standard of evaluation. Klompmaker *et al.* (2007) have developed an immersive mobile guide testing platform using panoramic imagery, which supports Wizard-of-Oz evaluations.

Though many mobile guides have now been created, there are a number of areas where research is still needed including:

- Hardware adaptation, e.g. Norrie and Signer (2005) experimented with the use of digital paper as an interface to a mobile guide
- New mixed reality interfaces and their effectiveness e.g. comparisons of map, AR and VR interfaces to the Camineo Guide by Mountain and Liarokapis (2007)
- Development of the concepts of mobile guide 'authorship' e.g. Kjeldskov and Paay (2007) who suggested that mobile guide authorship could be organised around a set of metaphors
- Incorporation of greater intelligence into the configuration of mobile guides, e.g. using agents (O'Grady *et al.* 2005)

- The creation of content collections and the integration of geospatial content management systems into mobile guides.
- Incorporation of decision support into LBS as Bäumer *et al*. (2007) have shown is desirable, for example, when trading off multiple criteria in the selection of a hotel

While the research community has created dozens of mobile guides and commercialised a handful, the commercial sector have developed the PND market to reach millions of users by building hardware/software integrated navigation devices for drivers. At present these devices are highly focussed on a single navigation use case, however, these systems are slowly becoming more like mobile guides with points of interest, 3D viewing and mobile social networking. It can be anticipated that these systems will ‘cross over’ at some point, when the mobile guides can bring content relevance and adaptivity to PND, and the PND can bring routing to the pedestrian use case.

4. Transport LBS

Intelligent transport systems (ITS) are a developing technology vision for information integration among the wide range of organisations and services active in transport planning and operations. These systems are referred to as ‘intelligent’ because their capabilities allow them to perform higher order operations such as situational analysis and adaptive reasoning. The ongoing challenge is to build a transportation system of the future that will be more efficient, less polluting and safer with users who were better informed. In the last two decades, ITS have progressed from the creation of institutions like the Intelligent Transport Systems and Services for Europe (ERTICO) to the development of ITS architectures (Bossom 2000) and the implementation of standards such as ISO 14813 (ISO 2007).

The key technologies that can enable this ITS vision are many of the same technologies that underpin LBS in general: geopositioning, wireless communications, mobile computing platforms, and spatial databases. The term *Telematics* has often been used by the transportation sector to refer to these technologies and applications, even though the term has a broader remit. In this section, the focus will be on those vehicle-based products and services that may be considered synonymous with mainstream LBS. These applications will be termed transport LBS and include driver assistance, passenger information, vehicle management and vehicle-to-vehicle applications.

4.1. *Driver assistance*

In the last few years the huge growth of PND systems has brought LBS technology to the consumer marketplace. However, today’s PND systems are still limited to the navigation use case and there is still great potential for further development. Rizos and Drane (2004) presented a layered conceptual model of the Vehicle Navigation System (VNS) as follows:

(1) The Electronic Street Directory (ESD) is the most rudimentary form of VNS and consists of a fixed in-vehicle screen or removable smartphone, PND or PDA, upon which map data can be panned and zoomed.
(2) The Electronic Vehicle Locator (EVL) is an enhancement of the ESD, and permits the current vehicle’s location determined by GPS to be displayed.

(3) The Electronic Navigation Assistant (ENA) makes use of digital road map (DRM) data to aid the driver using enhanced geopositioning via map-matching, best-route calculation and point of interest querying.
(4) The Server-assisted ENA (SENA) is the logical extension of the ENA, which can receive additional dynamic data such as congestion information via mobile data link and find the location of other drivers in a group.

The geopositioning capabilities required by the EVL, ENA and SENA pose some special challenges as GPS suffers from lowered availability and reliability in urban environments due to obstruction of the satellite signals in urban canyons, tunnels and multi-storey car parks (Drane and Rizos 1997). Improving the availability and performance of GPS in such environments may involve:

- Other signals-of-opportunity (e.g. digital TV, mobile telephony) in places where GPS reception will always be poor;
- Addition of inertial measurement units with accelerometers, odometers and gyroscopes for tunnels;
- Integration of other positioning infrastructures such as RFID.

This work is part of a significant effort towards what is more generally referred to as 'Ubiquitous Positioning' (Brzezinska 2004; Mok *et al*. 2006) which will be the foundation of further development of transport LBS for driver assistance.

The SENA is now perhaps the defining example of the transport LBS for driver assistance. In fact the SENA concept, if carried to its natural conclusion, means that all of the services can be accessed from a very 'thin' mobile device in the vehicle. The SENA device need not even be permanently installed within a vehicle, and the various concierge and LBS can be offered to all mobile users, whether in a vehicle or not. All they require is a mobile device with the necessary geopositioning and wireless communication link services. Rehrl *et al*. (2007) outline the design of such a multimodal, portable travel companion on smartphone with server assistance through the cellular network. They implemented the travel companion using two models: first, using J2ME and microbrowser on a Nokia smartphone wirelessly interfaced with a Siemens in-car navigation system; second, on a PDA running TomTom Navigator providing the GPS position and route information. In testing the operation with potential users, the transition from outdoor to indoor positioning was a problem, as was the complexity of the information on multimodal transfer. In general, Rehrl *et al*. (2007) identify the objective of providing information in a continuously changing context as the greatest challenge to multimodal travel companion design.

Driver assistance must also be divided into push (broadcast) and pull (requested) types of service. The main types of *broadcast* information relate in some way to traffic conditions, e.g., breakdown incident alerts, weather and road traction conditions, and information on traffic congestion, road restrictions and parking availability. In Europe, the Radio Data System (RDS) (Kopitzer and Marks 1998) has been the delivery channel for real-time traffic and weather information via the Traffic Message Channel (TMC) since the early 1990s (Traffic Management Channel Forum 2007). The TMC is a set of message formats that can be decoded by a TMC-equipped car radio or navigation system. Although the current channel is based on RDS, TMC can also be delivered via digital radio, Internet, or GSM/GPRS/UMTS systems. The Japanese government established the Vehicle Information and Communication System (VICS) that came online in 1996,

and currently provides real-time traffic and accident information at no charge to the drivers. Drivers can receive VICS information through a variety of channels, principally via special beacon receivers installed in vehicles, or by FM broadcasting.

On the other hand, information or services *requested* by a driver are best provided by a point-to-point wireless link, such as mobile telephony. The mobile phone (or an embedded modem that accesses the mobile phone network) is therefore the primary enabling technology for the request to, and delivery of information from central servers or call centres. For example, a driver may initiate an emergency services call, or the 'mayday' call could be generated automatically in the event of airbag activation (and the coordinates of the vehicle sent in a text message), as in the Automatic Crash Notification (ACN) scheme in the US and 'eCall' in Europe. Legal liability in driver assistance is an issue of growing importance as discussed by Wees and Brookhuis (2005).

In 1996, General Motors (GM) launched its OnStar system (Barabba *et al.* 2002). Initially, the devices to access navigation and Driver Assistance Services were installed in top-of-the-line vehicles. However, GM has expanded the range of vehicles it sells that have OnStar equipment factory-installed. Furthermore, several Japanese and German automakers have adopted the OnStar architecture. With over 4 million subscribers, OnStar is the most successful of the transport LBS services offered to vehicle owners. The range of Driver Assistance Services include: air bag deployment notification, emergency services, roadside and accident assistance, stolen vehicle tracking, remote door unlock, remote diagnostics, concierge services, route support, and general information services. These services are accessed via a mobile phone link, transmitting voice requests and responses, or data, from the vehicle to the OnStar call centres/servers, and visa versa.

4.2. *Passenger information*

Passengers planning to use public transport can obtain advice on their itinerary, with step-by-step instructions on which buses or trains to use, such as the mobile phone–based Navitime system that now has 2 million users in Japan (Arikawa *et al.* 2007a). Through such a service users can be informed of pedestrian routes, public transport options, fares, timings, progress en route, delays, entrances and exits through the integration of GPS positioning on the client and server-side routing queries. Such systems are being widely developed on PDAs and smartphones worldwide (Rehrl *et al.* 2007).

The obstacles to wide use of such tools are both software-based and cognitive in nature. Rüetschi and Timpf (2004) suggested that users perceived multimodal public transport journeys partly as network problems, and partly as 'node' problems i.e. they recognised that there were a lot of problems in changing bus to train, metro to metro and so on. They suggested that users have the greatest problems at nodes and that users need guidance in image terms, perhaps expressed in schematic geometry based on image schemata (Johnson 1987). Dillemuth *et al.* (2007) explore the choice of map scale in commercial PNDs supporting vehicle navigation, finding that the appropriate map scale is a function of the user's time geography, which is not currently modelled in existing systems.

Winter and Nittel (2006) set out a more comprehensive vision of the passenger and driver information problem. They argue that in transportation networks of the future drivers and pedestrians as well as other traffic items like parcels will be able to self-organise

by advertising transportation services and travel requirements using intelligent geosensor networks. These services and requirements can be reconciled by negotiation during 'communication windows' through small area MANETs. Winter and Nittel (2006) simulate the performance of a shared ride trip using a geosensor network and demonstrate its effectiveness and efficiency.

In addition to technological aspects, it is important to identify socio-economic and legal issues related to travel behaviour so that LBS can be designed to address the social and geographic context of use (Urry 2006). Understanding 'where, how, why' people travel, by different modes, is not only important for transport planners, but also for developers of commercial LBS that target drivers and passengers (Axhausen 2006).

4.3. *Vehicle management*

Vehicle management services are not, in the first instance, targeted to the driver or passenger of the vehicle, but to a central control centre. However, mobile technology and LBS can play a role, for example in the following areas:

- Fleets of trucks, couriers, taxis and other commercial vehicles can be managed using transport LBS applications such as Fleet Management Systems (FMS), which have information transmitted to them about each vehicle's position and speed;
- Emergency vehicles can be dispatched and monitored by FMS alongside incident management systems;
- Private vehicles can also be monitored by FMS on request or when it has been stolen (e.g. OnStar system), however there are important privacy issues involved;
- Electronic road tolling can be built on geopositioning of the vehicle as in Germany's TollCollect system for trucks with weight over 12t (Rangwala and McClure 2004);
- Remote vehicle diagnostics can be carried out through mobile data connections as in the OnStar system.

Given the wide range of technological solutions involved in vehicle management, standardisation of built-in technologies and interoperability of mobile device-based systems is highly desirable. Europe's Interoperability Directive on Electronic Road Toll Systems (European Union 2004) aims to ensure that the technology is interoperable and focuses on the long-term migration to GPS/Galileo. Ieromonachou *et al.* (2007) critically review the electronic tolling systems in UK and Norway.

4.4. *Vehicle-to-vehicle applications*

An application of transport LBS that is still under development is intelligent vehicle systems (IVS), specifically focusing vehicle-to-vehicle communication (V2V). This requires the installation of equipment in the vehicle that enables communication with other vehicles on the road, essentially forming a 'network on wheels'. These mobile *ad hoc* networks (MANETs) form the basis of applications like collision avoidance and road obstacle warning systems. Communication between vehicles means vehicles can collect and share more information about the environment than ever before. For instance, it is now possible

for vehicles to relay messages about accidents to approaching vehicles that otherwise would not have been able to slow down in time to avoid the collision.

V2V's developmental chronology began with vehicle-to-roadside (V2R) communication and later blossomed into direct V2V communication. V2R was originally driven by a special wireless protocol known as dedicated short–range communication (DSRC), which was later used for V2V communication. Current research endeavours are examining both V2V and the integration of V2V and V2R as a means for information dissemination. Some of the earliest research was conducted in the 1980s by the Association of Electronic Technology for Automobile Traffic and Driving in Japan. This research primarily focused on incorporating traffic and driver information with traffic management systems (Tsugawa 2005). Shortly thereafter, the EU launched a successful project from 1987 to 1994 known as PROMETHEUS, which had its roots in V2V (Walker 1992). The prototype achieved a high standard of autonomous driving in real traffic conditions and proved to be a significant contribution to driving safety.

These projects opened the door for later cooperative driving systems including the automated 'platooning' systems of the PATH project (Hedrick *et al*. 1994), as well as the EU's 'Chauffeur' project (Gehring and Fritz 1997) and the ARCOS project (Blosseville *et al*. 2003). In 1997, California's PATH (Partners for Advanced Transit and Highways) team conducted a demonstration of a set of vehicles that transmitted relevant vehicle trajectory data to nearby vehicles. The vehicles were able to autonomously drive with equal speed and equal gap distances. Similarly, the ARCOS project used the vehicle's adaptive cruise control mechanism to communicate the vehicle's state among neighbouring vehicles in order to notify of hazardous events, preventing vehicles from leaving the road and avoiding collisions. Europe's Chauffer project was also developed as a means of automatic platooning and functioned through sharing acceleration and deceleration information.

Research in the next phase was conducted in Europe with the German-French inter-vehicle hazard warning (IVHW) project (Chevreuil 2002), the German FleetNet project (Hartenstein *et al*. 2001), and the EU's Cartalk2000 project (Morsink *et al*. 2002). The IVHW project was designed to evaluate common traffic safety concepts for European highway traffic. Some of its functions included accident and congestion warning, traffic routing, platooning, lane change assistance, and intersection assistance, among others (Tsugawa 2005). Germany's Fleetnet project was specifically designed to examine multi-hop *ad hoc* communication networks for V2V. Cartalk2000 utilised an *ad hoc* radio network to transmit information about incidents, emergencies, or congestion from preceding vehicle(s) to vehicles using both V2V and V2R.

Some of the research challenges for V2V include developing protocols that are capable of handling the MANET demands where vehicles are seamlessly integrated and dis-integrated within each *ad hoc* network. Networking architecture is also reliant on the medium into which the signal is broadcast and the common wireless problems encountered with each, such as in the microwave or infrared spectrum. An effective V2V safety system needs to be integrated at the physical, networking, and application levels, and a working resolution to these challenges has yet to be established. On top of this careful consideration is needed in how the system should optimally interact with the driver to warn of impending crash scenarios as well as how to handle a lack of technology penetration with all vehicles on the road. Examples of current research geared towards these areas includes research by Saito *et al*. (2005) for developing new transmission

protocols, research by LeBrun *et al.* (2005) for examining efficient *ad hoc* message passing schemes, and research by Koike *et al.* (2005) for increasing data capacity throughput.

5. Location-based gaming

Location-based games can be defined as computer games in which the real world location of the player has an influence on the way the game develops (Benford *et al.* 2004b). Other terms that are used for multiplayer games taking place in urban environments include: 'urban gaming' or 'street games'. The main characteristics of location–based games have been specified by Capra *et al.* (2005) as mobility, interaction in public, location specificity and integration of the physical and digital world. Magerkurth *et al.* (2005) use the term 'pervasive gaming' to describe an emerging genre in which traditional, real-world games are augmented with computing functionality, or purely virtual computer entertainment is brought back to the real world.

Location-based games can be divided into those derived from 'outdoor games' and those derived from board games/computer games (Peloschek 2006). The first type of game can be characterised as combining outdoor activities like hunting, hiding or chasing with additional game elements provided by mobile technology. Such additional elements are based around interaction and communication. Games derived or adapted from board/computer games generally transfer them into the real world, where they are played by real players (Benford *et al.* 2005).

Geocaching is an example of a non-competitive location-based game that has a large player community. Geocaching is an outdoor treasure hunting game in which the participants use a GPS receiver or other navigational techniques to hide and/or seek containers (called 'geocaches' or 'caches') anywhere in the world. A typical cache is a small waterproof container containing a logbook and 'treasure', usually toys or trinkets of little value. Today, well over 440,000 geocaches are registered on various websites devoted to the sport. Geocaches are currently placed in 222 countries around the world and on all seven continents, including Antarctica (Gründel 2007). LBS tools have also been developed to support orienteering (László 2005).

Location-based art is in its infancy but it is already clear from some early experiments that there is great interest from the public in 'locative media' as seen on http://www.gpsdrawing.com/ for example. Real time exhibits of mobile user behaviour and calling have been assembled, as for example in 'Mobile Graz' (Ratti *et al.* 2005).

Examples of Location-based games:

- Pac Manhattan (http://www.pacmanhattan.com)

Pac-Manhattan is a large-scale urban game that utilizes the New York City grid to recreate the 1980's video game Pac-Man. A player dressed as Pac-Man runs around the Washington square park area of Manhattan while attempting to collect all of the virtual 'dots' that run the length of the streets. Four players dressed as the ghosts Inky, Blinky, Pinky and Clyde will attempt to catch Pac-man before all of the dots are collected. Using cell-phone contact, Wi-Fi internet connections, and custom software designed by the Pac-Manhattan team, Pac-man and the ghosts will be tracked from a central location and their progress will be broadcast over the internet.

- Tourality (http://tourality.com)

Tourality combines outdoor activity with virtual gaming experience. Equipped with a mobile phone and GPS the challenge is to reach particular places before your opponents. A place is a certain point on a virtual map that has to be reached in reality. While the players are on their way, the real position is tracked by GPS and shown on the display of the mobile phone. As the position of all participating players as well as the target places are known to all players, a real-time challenge and comparison is given.

- Uncle Roy All Around You (http://www.uncleroyallaroundyou.co.uk)

Uncle Roy All Around You is a game where street players use handheld computers to search for 'Uncle Roy', guided by an interactive map and messages from Online Players. The role of the Online Players is to cruise through a virtual map of the same area, searching for Street Players to help them find a secret destination. The game is time restricted and players must work together by using web cams, audio and text messages.

- The Journey (http://www.mopius.com/mobilegames/3journey2.php)

The Journey is an adventure game for mobile phone users. The player is in the role of an infamous detective and has to solve a mysterious case not only by making it through the story, but also by visiting a variety of different locations.

- Mogi (http://www.mogimogi.com/mogi.php?language=en)

In this game virtual objects have to be collected in the real world by approaching specific locations with the mobile phone. The collected virtual objects can be traded and exchanged.

- Undercover 2 (http://www.undercover2.com)

Undercover 2 is a multiplayer game for mobile phones. Players can adventure together through a persistent game world, creating and customising their characters, developing skills, forming clans with friends, conquering territory, buying and selling valuable items, challenging enemies and engaging in elaborate missions. The action unfolds on the streets of the real world, as the game incorporates maps for many cities.

- Can You See Me Now? (http://www.canyouseemenow.co.uk/)

Can You See Me Now? is a chase game played online and on the streets. Players are dropped at random locations into a virtual map of a city. Tracked by GPS, runners appear online next to the player. The runners use handheld computers showing the positions of online players to guide them in the chase. The players are supposed to flee down virtual streets, send messages and exchange tactics with other online players. If a runner gets within 5 m of you, a sighting photo is taken and your game is over.

Location-based gaming design requires some novel considerations in the context of LBS application design. Opperman *et al.* (2006) show that as well as application design for the real world gaming environment the game designer needs to work with digital media and the (spatially variable) ubiquitous computing infrastructure. Uncertainty in position is a concern in gaming as it affects gaming integrity: users' self reporting is influenced by landmark positions relative to their real location (Benford *et al.* 2004b), and GPS positions suffer from multipath errors in cities. McCarthy and Curran (2007) proposed a game

architecture including RFID positioning to tackle this problem. Location-based games also need a compelling 'narrative', whether one that aims to transform the real environment e.g. school playing fields to African savannah (Benford *et al*. 2004a) or whether the game is a location–sensitive interactive play for voices (Blythe *et al*. 2006). Also, interfaces for location-based gaming pose novel challenges: for example, gamers experience location as a dimension of interaction, making it easier to absorb complex information (Reid *et al*. 2005).

6. Assistive technology and location-based health

The navigation needs of blind users have attracted substantial research work in recent years (Golledge 1999). MoBic (Mobility of Blind and elderly people) was one of the earliest systems designed to aid visually impaired people with pedestrian navigation and covered both planning a route to a specified destination as well as guiding the user along the route (Petrie *et al*. 1997). MoBic consisted of a MoPS (MoBic Pre-Journey System) and a MoODS (MoBic Outdoor System). The basic function of the MoPS was to familiarise the user with the travel environment via a map as well as to plan their journey before traveling. The MoPS calculated a route by taking into consideration user preferences while optimising parameters such as time to travel or distance to walk (Strothotte *et al*. 1996). The MoODS integrated the information provided by the MoPS with the user's current location (provided by differential GPS) to assist the traveler with audio directions and warnings (Petrie *et al*. 1997).

Though research on technological aids to the blind has been conducted for at least two decades, most of the early systems were heavy, cumbersome and impossible to use as day-to-day mobility support. However, with the arrival of powerful smartphones/PDAs it has been possible to develop systems for mobility support on 'standard' mobile devices that can be used without stigma or special training (Goodman *et al*. 2004). Since screen readers for mobile devices can provide audio-description of their user interfaces, 'universal access' to LBS is becoming a reality in the mobility assistance field.

'Drishti' is an indoor/outdoor wireless pedestrian navigation system designed to aid visually impaired and disabled individuals with navigation. Like MoBic Drishti allows users to pre-plan a route to a given destination and provides dynamic assistance to the user as they travel along a route (Ran *et al*. 2004). Routing is adapted to personal preferences as well as the shortest route. The system uses DGPS and dead reckoning for outdoor positioning and proprietary ultrasound sensing for indoor navigation. The wireless capabilities of Drishti allows for dynamic adaptivity, such as real time annotation of the route with unmarked obstacles like potholes. This information can be downloaded to the user's device, or if noted by the user for the first time, it can be uploaded to the server from the device.

NOPPA, a GPS-based personal navigation and information system, provides public information and pedestrian guidance for public transportation users designed primarily for visually impaired users (Virtanen and Koshinen 2004). NOPPA was developed by VTT in Finland and was successfully implemented in an area covering three neighbouring cities. The system can seamlessly navigate the users through different means of transportation including sidewalks, buses, trains, and trams. The clients are mobile devices such as smartphone or PDA with GPS, voice synthesis, and wireless connection capabilities. The information server interprets user requirements and accesses various different

databases on behalf of the user when requesting real-time information such as bus arrival times, weather and services such as route planners.

Another navigation research project for the visually impaired is Remote Guidance System (RGS), which provides a visually impaired user with the remote assistance of a sighted guide. The user is equipped with a digital camera worn like a necklace around the user's neck, which sends images of the user's current location over a network connection to a remotely located sighted guide (Hunaiti *et al*. 2006). The user is also equipped with a GPS device that provides an estimated location of the user to be displayed on a digital map for the sighted guide. The sighted guide, at the remote location, has access to information about the surrounding environment stored in a GIS database. The user has a voice link to the sighted guide and thus can make requests about the environment as well as receive directions and other information.

McCreadie *et al*. (2006) outlined the design, testing and implementation of the LBS4all system for mobility support, based on the Camineo mobile guide platform. As the Camineo platform is web-based it can be adapted, using the principles of Universal design, for the needs of blind users (with audio description) and users with poor sight (using 'large print' stylesheets). The LBS4all system developed an address describer application that used an integrated digital compass to allow blind, partially sighted or older people to use a LBS to find the address that they were pointing at with their mobile device. Gaunet (2006) has studied the language of guidance to determine the optimum interface to blind navigation and Goodman *et al*. (2005) has studied the use of landmarks in mobility guidance for older people, finding that a mobile device showing landmarks can significantly outperform a paper map in navigation tasks.

Besides these research projects, there are several standalone commercial navigation products designed especially for the blind and visually impaired based on GPS, for example, Sendero GPS (SenderoGroup 2007) and Trekker by VisuAid (VisuAide 2007). The difference is that the Trekker application runs on a standard PDA with touch screen adaptor while the Sendero GPS application runs on the BrailleNote device. These two products are similar to commercial car and pedestrian navigation systems with the addition of voice and Braille interfaces to the pedestrian guidance.

There is a small but rapidly growing group of location-based health applications, which are focused on outdoor exercise and health monitoring. This work is a subset of the work on travel behaviour in which tracking of individuals is undertaken to explore their mobility and spatial behaviour (Krygsman *et al*. 2007, Kwan 2007). LBS are useful tools for the measurement of exercise and fitness (Ahtinen *et al*. 2007) and have been used for the study of children's health (Mackett *et al*. 2007). Applications to monitor vulnerable people using LBS and the management of teams to deliver health care have also been proposed (Hansen *et al*. 2005).

7. Applications yet to come

The range of LBS applications reviewed in this article is extremely diverse, and there is little conceptual or technical integration between them at this point. However, as architectures for mobile applications development begin to gain penetration across disciplines and territories, it can be expected that these application areas will become more conscious of the lessons and insights to be gained from exploring experiences in neighbouring research areas.

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